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(71) Applicant(s)
Ford Global Technologies, Inc.
(Incorporated in USA - Michigan)
600 Parklane Towers East, One Parklane Boulevard, Dearborn, Michigan 48126, United States of America

(72) Inventor(s)
Wengang Dai
Nizar Trigui
Rodney John Tabaczynski

(74) Agent and/or Address for Service
A. Messulam & Co. Ltd
43-45 High Road, BUSHEY HEATH, Herts, WD2 1EE, United Kingdom

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(56) Documents Cited
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(54) Abstract Title
Real-time engine misfire detection method involving the calculation of a Karlovitz number

(57) A method of detecting internal combustion engine misfires by generating a predicted Karlovitz number as a function of different engine operating conditions such as the air fuel ratio (AFR), the engine speed, the amount of exhaust gas recirculation (EGR), spark-ignition (SI) timing and the air flow rate. The predicted Karlovitz number is then compared against the threshold Karlovits number in which misfire occurs. The threshold Karlovitz number is determined from a model for misfire predictions in engines and is stored in the electronic engine controller (EEC). A misfire is reported if the predicted Karlovitz number is greater than the threshold Karlovitz number. In another aspect of the invention, the predicted Karlovits number is generated from submodels of laminar flame speed, laminar flame thickness, turbulence intensity, and turbulence integral length scale.

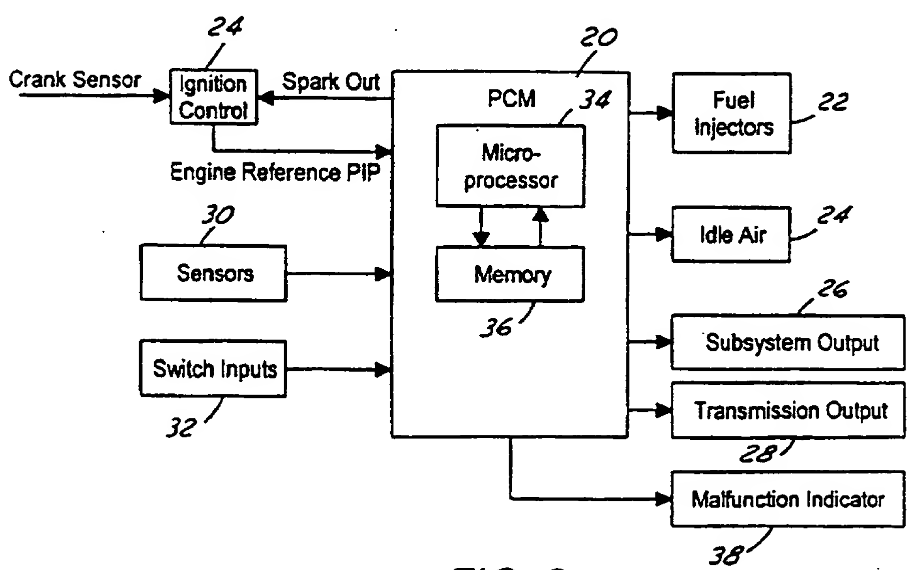

FIG. 2

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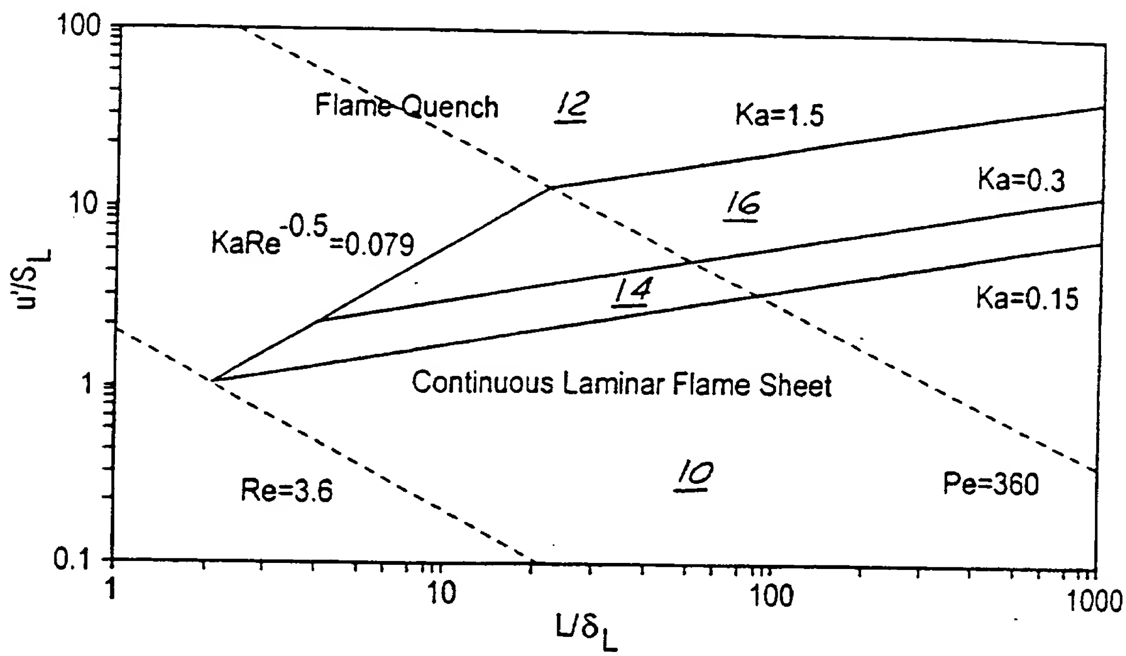
100
10
1
0.1
u'/S_L
Flame Quench
12
Ka=1.5
Ka=0.3
16
KaRe^-0.5=0.079
14
Ka=0.15
Continuous Laminar Flame Sheet
Re=3.6
10
Pe=360
1
10
100
1000
L/δ_L

FIG. 1

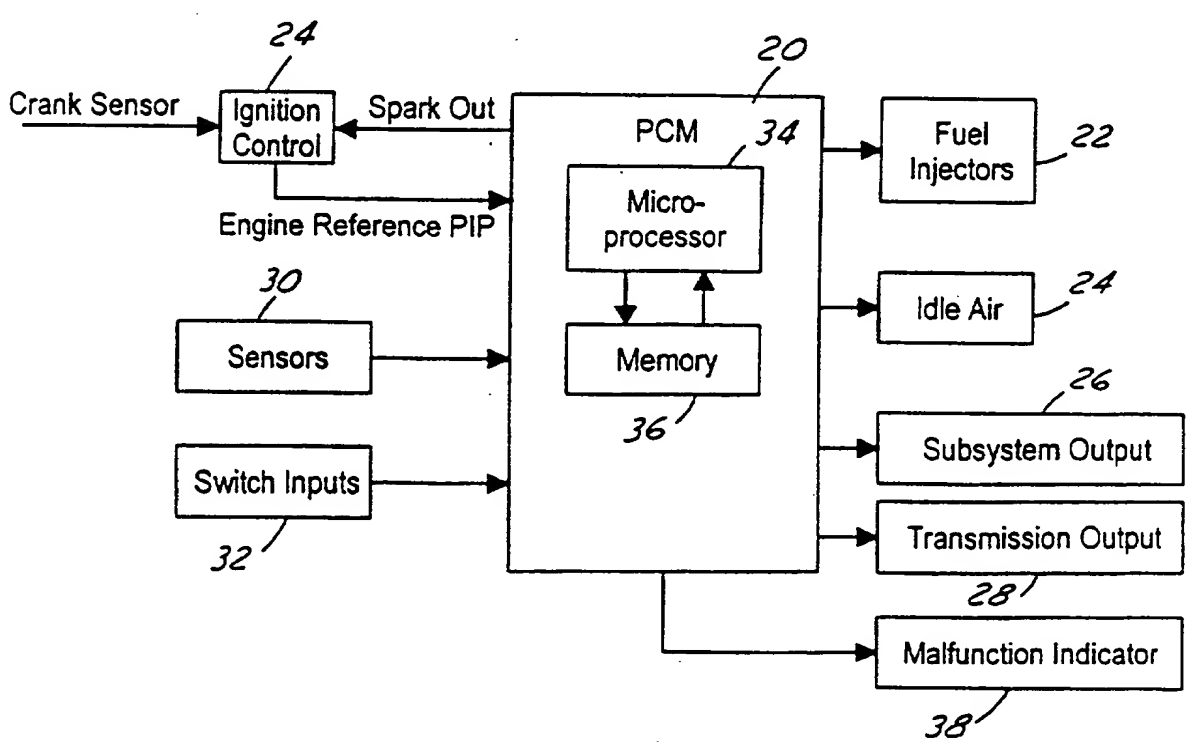
24
20
Crank Sensor
Ignition Control
Spark Out
PCM
34
Fuel Injectors
22
Micro-processor
Engine Reference PIP
30
Idle Air
24
Sensors
Memory
26
36
Subsystem Output
Switch Inputs
Transmission Output
32
28
Malfunction Indicator
38

FIG. 2

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REAL-TIME ENGINE MISFIRE DETECTION METHOD

The present invention relates generally to internal combustion engines and, more particularly, to an automobile engine misfire detection system and method based on mathematical models for spark-ignited engines and misfire prediction.

Engine misfire can occur for several reasons such as the absence of spark in the cylinder, poor fuel metering, inadequate compression, or other similar conditions. As a result of engine misfires, an increased amount of unburned combustion by-products are passed through the catalytic converter. Over time, engine misfiring can cause damage to the catalyst in the catalytic converter and, consequently, increase the amount of combustion by-products emitted into the atmosphere.

Because engine misfire can effect engine emissions, government regulatory agencies require that the vehicle fuel control system detect and indicate emission malfunctions such as misfiring. This engine misfiring information is typically collected and stored in computer memory associated with the vehicle engine for later downloading and analysis at a service centre.

A variety of schemes have been developed for misfire detection including: (1) ionisation current monitoring, (2) combustion pressure detection - which requires a pressure transducer in every engine cylinder, (3) cylinder pressure reconstruction using crankshaft speed variation, and (4) measurement of crankshaft angular velocity as well as other techniques based on crankshaft angular velocity and/or acceleration. There are several drawbacks to these present misfire detection methods. The first two methods require additional sensors or hardware which increase the system cost and complexity. In addition, the misfire detection methods based on crankshaft velocity or acceleration are prone to detection errors because they are based on four major assumptions: (1) a constant co-efficient driveline

model, (2) a constant load torque, (3) a torsionally rigid crankshaft, and (4) non-overlapping firing pulses. These assumptions can result in a normal combustion cycle being counted as a misfire, and a misfired combustion cycle going undetected.

According to the present invention, the foregoing and other object and advantages are attained by a method of detecting internal combustion engine misfires by generating a predicted Karlovitz number as a function of different engine operating conditions such as the air fuel ratio (AFR), the engine speed, the amount of exhaust gas recirculation (EGR), the spark-ignition (SI) timing, and the air flow rate. The predicted Karlovitz number is then compared against the threshold Karlovitz number at which misfire occurs. The threshold Karlovitz number is determined from a model for misfire predictions in engines and is stored in the electronic engine controller (EEC). A misfire is reported if the predicted Karlovitz number is greater than the threshold Karlovitz number.

Preferably, the predicted Karlovitz number is generated from submodels of laminar flame speed, laminar flame thickness, turbulence intensity, and turbulence integral length scale.

An embodiment of the present invention accurately detects engine misfires using sensors commonly found in engine control systems.

The invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a Leeds diagram representing an engine misfire model; and

Figure 2 is a schematic diagram of an engine control and misfire detection system according to one embodiment of the present invention.

In a conventional spark-ignited engine, the fuel and air are mixed together in the intake system, inducted through the intake valve into the engine cylinders, mixed with residual gas, and then compressed. Under normal

operating conditions, combustion is initiated toward the end of the compression stroke by the spark plug. Following the flame kernel formation, a flame develops, propagates through this essentially pre-mixed fuel/air and residual burned gas mixture until it reaches the combustion chamber walls, and is extinguished.

Like most processes in engines, misfire is a very complicated phenomena. Attempts to simulate misfire can easily result in extremely complex, yet inefficient, models. Misfire typically occurs in a spark-ignition engine when the spark fails to ignite the mixture, or the combustion stops and the flame quenches in the kernel stage. Partial misfire occurs when the flame quenches after being fully developed, or flame growth becomes so slow that combustion takes place in a small fraction of the mixture and is incomplete when the exhaust valve opens. To date, no flame kernel model has been developed with the capability of simulating misfire and misfire limits.

Although no satisfactory flame kernel model has been developed, the characteristics of pre-mixed turbulent combustion have been modelled based on empirical data. Specifically, researchers from the University of Leeds analysed experimental data taken in a combustion bomb and defined boundaries for each pre-mixed turbulent combustion regime. The Leeds diagram is the basis for the present misfire engine model and is shown in Figure 1.

Referring to Figure 1, the boundaries associated with pre-mixed turbulent combustion are represented by the continuous laminar flame sheet region 10, the flame quench region 12, region 14 defining the break-up of the continuous laminar flame sheet, and the fragmented reaction zone 16 where flame quenching begins to develop. In Figure 1, a misfire occurs where the Karlovitz number (Ka) is greater than or equal to 1.5 if the turbulent Reynolds number (Re) is greater than or equal to 360. Sub-models define the parameters of the Leeds Diagram in Figure 1. These include the turbulence intensity (u'), turbulent integral length

scale (L), laminar flame speed (S_L) laminar flame thickness (Δ_L) and Karlovitz number (Ka). Thus, as shown in Figure 1, the threshold Karlovitz value is 1.5.

The misfire detection method of the present invention generates a predicted Karlovitz number (Ka_p) from engine operating parameters in real-time and compares this value to the threshold Karlovitz number (Ka_t). A misfire is indicated if Ka_p exceeds Ka_t. Through experimentation, it has been determined that certain engine operating parameters are related to misfire detection. These include EGR rates, air fuel ratio, engine speed, spark timing and air flow rate. The relationship between these engine operating parameters and their effect on combustion is described in SAE paper number 982611 entitled "Regimes of Pre-Mixed Turbulent Combustion and Misfire Modelling in SI Engines" which is herein incorporated by reference. As discussed in the referenced paper, different engines shared the same regimes of turbulent combustion. This normally takes place in the continuous laminar flame sheet region 10, break-up region 14, and fragmented reaction zone 16.

Figure 2 shows a schematic diagram of one embodiment of the present misfire detection scheme based on the Leeds Diagram of Figure 1. As shown in Figure 2, powertrain control module (PCM) 20 controls the engine operation by regulating the fuel supply, spark timing, and air flowing to the engine. Fuel is metered by injectors 22 and spark timing is regulated by ignition control module 24 in response to spark-out signal from PCM 20. Airflow is represented by idle air block 24. The engine operation is further controlled by the PCM via the subsystem output module 26 which represents, for example, the EGR control valve.

PCM 20 is also responsible for regulating transmission output 28 by, for instance, controlling the shift solenoid. PCM 20 receives as inputs the engine reference PIP, sensor input 30 and switch inputs 32. Sensors 30 represents the cam profile, mass airflow sensor (MAF), manifold absolute

pressure sensor (MAP), fuel flow and EGR flow, for example. Switch inputs 32 represent such things as the air conditioning and parking brake.

PCM 20 includes a microprocessor 34 an associated memory 36. Memory 36 stores the misfire model of Figure 1 which provides the threshold Karlovitz value (Ka_t). Microprocessor 34 is designed to generate, in real-time, the predicted Karlovitz number based upon sensor inputs 30. When Ka_p exceeds the Ka_t, the misfire information is collected and stored in memory 36. Furthermore, if the percentage of misfires out of the total number of firing events exceeds regulatory minimum, the malfunction indicator 38 is activated to signal to the operator that the engine system should be tested. The misfire data collected in memory 36 can then be downloaded at the vehicle service centre during diagnostic testing.

The generation of Ka_p will now be described. Ka_p is defined as follows:

$$Ka_p = 0.157\ (u'/S_L)^2 R_e^{-0.5} \qquad (1)$$

wherein the turbulent Reynolds number is defined as:

$$R_e = u'L/V \qquad (2)$$

wherein u' represents the turbulent intensity, S_L represents the laminar flame speed, L represents the turbulence integral length scale, and V represents the kinematic viscosity.

The laminar flame speed is a function of the residual gas fraction (R_f) and is defined as:

$$S_L\ (R_f) = S_{L,\emptyset}\ (T/T_o)\ (P_o/P)\ (1-4.1\ R_F + 4.7\ R_F^2) \qquad (3)$$

wherein T is temperature, T_o is standard temperature, P is pressure, and P_o is standard pressure.

In equation (3), alpha and beta represent functions of the air/fuel ratio.

In addition, the laminar flame thickness is defined as:

$$_L = V/S_L \qquad (4).$$

The turbulent intensity can be derived from a turbulence model defined as:

$$dk/dt = P^k_{dens} + P_{sq} + P_{sh} + F^k_{int} + P_{turb} \qquad (5)$$

wherein the turbulence dissipation is defined as:

$$= (C_\epsilon k^{3/2})/L \qquad (6)$$

Thus, the turbulent intensity is defined by:

$$u' = (3k/2)^{1/2} \qquad (7)$$

and the integral length scale is represented by:

$$L = L_o \ (k_o/k)^{1/2} \qquad (8)$$

Alternatively, the turbulent intensity and integral length scales can be defined as:

$$u' = 0.25\ U_{piston} \qquad (9)$$

$$L = 0.33\ H_{clearance} \qquad (10)$$

Wherein U_{piston} is the piston mean speed and $H_{clearance}$ represents the piston clearance at Top Dead Centre.

In operation S_L, $_L$, u', and L are derived from the sensor inputs to the PCM 20. Specifically, AFR, EGR flow, SI timing, and engine RPM are sensed or derived from sensor inputs such as MAF, MAP and fuel flow. Once Ka_p is determined, it is compared to Ka_t which, in this case, is equal to 1.5. If Ka_p exceeds Ka_t, then a misfire event is indicated and stored in memory 36.

Alternatively, rather than calculating Ka_p in real-time for each combustion cycle, a lookup table of Ka_p values can be generated and stored for each unique set of engine operating parameters. In such an embodiment, PCM memory 36 must be sufficiently large to store all the possible values of Ka_p for each unique set of engine operating parameters. The benefit, however, would be that a microprocessor having reduced computational speed could be used in place of the microprocessor required to operate the misfire detection in real-time.

CLAIMS

1. A method of detecting misfire of an internal combustion engine comprising the steps of:

determining a plurality of engine operating parameters;

generating a predicted Karlovitz number (Ka_p) as a function of said plurality of engine operating parameters;

comparing Ka_p to a threshold Karlovitz number (Ka_t) representing the value at which misfire occurs; and

indicating an engine misfire event if $Ka_p > Ka_t$.

2. A method as claimed in claim 1, wherein the step of determining a plurality of engine operating parameters includes the steps of:

determining an AFR value indicative of the air/fuel ratio of the in-cylinder mixture of the engine;

determining an RPM value indicative of the engine speed;

determining an EGR value indicative of the amount of exhaust gas recirculation in the engine; determining an SI value indicative of the spark-ignition timing of the engine; and

determining an airflow valve indicative of the engine intake airflow.

3. A method as claimed in claim 2, wherein the step of generating a predicted Karlovitz number (Ka_p) includes the steps of:

generating a laminar flame speed value (S_L), a laminar flame thickness value ($_L$), a turbulent intensity value (u'), and turbulence integral length scale value (L) as a function of said AFR, RPM, EGR, SI and airflow values; and

generating Ka_p as a function of S_L, $_L$, u', and L.

4. A method as claimed in claim 1, wherein the step of generating a predicted Karlovitz number (Ka_p) as a function of said plurality of engine operating parameters

12. A method as claimed in claim 10, wherein the step of generating a predicted Karlovitz number (Ka_p) includes the steps of:

determining an AFR value indicative of the air/fuel ratio of the in-cylinder mixture of the engine;

determining an RPM value indicative of the engine speed;

determining an EGR value indicative of the amount of exhaust gas recirculation in the engine;

determining an airflow value indicative of the engine intake airflow;

generating a laminar flame speed value (S_L), a laminar flame thickness value ($_L$), a turbulent intensity value (u'), and turbulence integral length scale value (L) as a function of said SI value and said AFR, RPM, EGR and airflow values; and

generating Ka_p as a function of S_L, $_L$, u', and L.

13. A method as claimed in claim 10, wherein the step of generating a predicted Karlovitz number (Ka_p) as a function of said plurality of engine operating parameters includes calculating Ka_p for each combustion cycle in real-time.

14. A method as claimed in claim 10, wherein the step of generating a predicted Karlovitz number (Ka_p) as a function of said plurality of engine operating parameters includes retrieving Ka_p from a table of values indexed by said engine operating parameters for each combustion cycle.

15. A method of detecting misfire of an internal combustion engine substantially as hereinbefore described with reference to the accompanying drawings.

16. A powertrain control module for controlling the operation of an internal combustion engine substantially as

hereinbefore described with reference to the accompanying drawings.

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INVESTOR IN PEOPLE

Application No: GB 0009110.8
Claims searched: All

Examiner: Carol Ann McQueen
Date of search: 7 September 2000

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.R): GIN (AAJCR, AHHB)

Int Cl (Ed.7): B60R 16/02, G01M 15/00

Other: ONLINE: EPODOC, WPI, JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	EP 0716298 A2 (FORD)	
A	US 5287282 A (FUJI)	
A	US5571958 A (HOSHINA)	

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.